Automatic one-loop calculation of MSSM processes with GRACE

J. Fujimoto[a], T. Ishikawa[a], M. Jimbo[b], T. Kon[c] and M. Kuroda[d]

[a]KEK, Oho, Tsukuba, Ibaraki 305-0801 Japan

[b]Tokyo Management College, Ichikawa, Chiba 272-0001, Japan

[c]Seikei University, Musashino, Tokyo 180-8633, Japan

[d]Meiji Gakuin University, Totsuka, Yokohama 244-8539, Japan

We have developed the system for the automatic computation of cross sections, `GRACE/SUSY` , including the one-loop calculations for processes of the minimal supersymmetric extension of the the standard model. For an application, we investigate the process $e^+e^- \to Z^0h^0$.

1. Introduction

Supersymmetry (SUSY) between bosons and fermions at the unification-energy scale is one of the most promising hypothesis, which is expecteted to resolve the remaining problems in the standard model (SM). In particular, the minimal supersymmetric extension of the SM (MSSM) [1] has been extensively studied in the last decade due to the simplicity.

For more than ten years, we have been developing the system of the automatic computation of the high energy physics processes. The system for the computation of the SM, `GRACE`, has been published in [2].

In including the interactions of SUSY particles in the `GRACE` system, we have made several modifications and the expansion of the system [3,4]. As the first outcome from `GRACE/SUSY`, we have published a package of event-generator, `SUSY23`, which contains 23 specific SUSY processes for $e^+e^- \to$ 2-body and 3-body [5]. At this stage, the model definition files are based on the Hikasa's Manual [6].

Recently, we have constructed the complete lagrangian of the MSSM [7] using the European convention: namely, the positive chargino is called a particle and the ranges of μ and $\tan\beta$ are defined as $0 \leq \tan\beta \leq 1$ and $-\infty \leq \mu \leq +\infty$. Thus we have published the new version of `GRACE/SUSY` (`GRACE v2.2.0`) [8], which is available from `http://minami-home.kek.jp/` .

In the world, there exist several other groups independently developing the systems of the automatic computation in the SM with different methods [9,10,11,12], and also developing the systems of the automatic computation in the MSSM, `FeynArts-FormCalc` [13] and `CompHEP` [14].

In this paper, we present the latest development of the `GRACE/SUSY` system including the one-loop calculations in the MSSM.

2. GRACE/SUSY/1LOOP

2.1. Renormalization scheme

In the the MSSM, several particles are mixed states, so there are three kinds of way of introducing wavefunction renormalization constants. We adopt the renormalization scheme of the MSSM as follows:

- the gauge-boson sector: the conventional approach [15]
  (Renormalization constants of wavefunctions are introduced to unmixed bare states and mass counterterms are introduced to mixed mass eigenstates.)

- the Higgs sector: the Dabelstein's approach [16] ; the chargino sector and the neutralino sector: the Kuroda's approach [17] (see also

[18])
(Renormalization constants of wavefunctions are introduced only to unmixed bare states.)

- the matter-fermion sector and the sfermion sector: the Kyoto approach [19]
(Renormalization constants of wavefunctions are introduced only to mixed mass eigenstates.)

2.2. How to check the system

For the tree-level calculations, we first check the gauge invariance of amplitudes at a point of the phase space before the integration. In the GRACE system, the gauge invariance check is automatically carried out using the covariant gauge and the unitary gauge. In the SM, we have also checked GRACE with the non-linear gauge [20]. In the MSSM, we have already checked the gauge invariance for 582,102 processes with up to six-external particles within quadruple precision [21].

For the one-loop calculations, we check the invariance of cross sections varying three parameters, the UV constant ($C_{\rm UV}$), the fictitious photon mass (λ) and the cutoff energy of the soft photon ($k_{\rm c}$). As an example of the invariance checks, the result for the process $e^+e^- \to \tilde{\chi}_2^+\tilde{\chi}_2^-$ at $\sqrt{s} = 1900$ GeV is shown in ref. [22], using the same input parameters as in ref. [23].

2.3. Application

As an application, we consider the production of the lighter CP-even Higgs h^0 [24]. First, we compare the CP-even Higgs masses, M_{h^0} and M_{H^0}, with the results of the Dabelstein [16]. In Table 1 and Table 2, the tree masses, one-loop masses are compared using parameters in (1) and (2). We can claim the agreement is satisfactory.

$$
\begin{aligned}
M_Z = 91.187,\ M_W = 80.35,\ m_t = 175,& \\
M_{A^0} = 300,\ \mu = -100,\ M_2 = 400,& \\
\tilde{m}_{\tilde{f}_L} = \tilde{m}_{\tilde{f}_R} = m_{sf} = 500,\ \theta_f = 0& \qquad (1)\\
\text{for all sfermions,}& \\
\text{(masses in GeV).}&
\end{aligned}
$$

$$M_{A^0} = 200,\ m_t = 150 \quad \text{(in GeV)}, \qquad (2)$$

We have investigated the process $e^+e^- \to Z^0h^0$ [24], using the input values (1) except $M_W = 80.423$ GeV, $m_t = 174$ GeV, $M_{A^0} = 150$, 250 and 350 GeV. We found that the cross sections are not sensitive to M_{A^0} at $\sqrt{s} = 500$ GeV. In Figure 1 we show the results for $M_{A^0} = 150$ GeV.

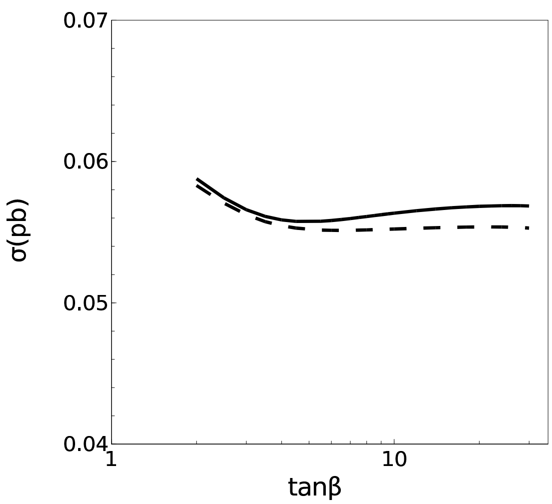

Figure 1. Cross-sections for $e^+e^- \to Z^0h^0$. The solid (dashed) line shows the radiative corrected (Born) cross sections in pb at $\sqrt{s} = 500$ GeV.

3. Conclusion and outlook

We have developed the system for the automatic computation of cross sections, GRACE/SUSY, including the one-loop calculations for processes in the MSSM. For an application, we investigate the process $e^+e^- \to Z^0h^0$.

Remaining tasks for us are:

- checking GRACE/SUSY/1LOOP with the non-linear gauge in the MSSM
- checking GRACE/SUSY/1LOOP for the invariance of cross sections on the UV constant in

$\tan\beta$	m_{h^0}	M_{h^0}		m_{H^0}	M_{H^0}	
	tree	1-loop	Dabelstein	tree	1-loop	Dabelstein
0.5	53.11506	93.1	93.2	309.0208	352.4	352.1
2.0	53.11506	83.8	84.0	309.0208	312.3	312.3
5.0	83.55589	106.0	106.2	302.2143	302.9	303.0
10.0	89.20395	110.5	110.8	300.5955	300.8	300.9
30.0	90.96377	112.9	113.7	300.0677	300.1	300.2

Table 1. The tree masses and the full one-loop masses of h^0 and H^0 are compared with those given by Dablestein [16] for the values of the input parameters given in (1).

$\tan\beta$	m_{h^0}	M_{h^0}		m_{H^0}	M_{H^0}	
	tree	1-loop	Dabelstein	tree	1-loop	Dabelstein
0.5	51.18954	79.0	79.2	213.7632	243.8	243.6
2.0	51.18954	69.2	69.5	213,7632	216.7	216.7
5.0	82.65397	95.5	95.7	203.6747	204.4	204.4
10.0	88.93069	101.2	101.5	201.0134	201.3	201.3
30.0	90.93177	103.6	104.2	200.1162	200.2	200.2

Table 2. The tree masses and the full one-loop masses of h^0 and H^0 are compared with those given by Dablestein [16] for the values of the input parameters given in (2).

other processes, for example, sfermion productions and neutralino productions.

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